



Achieving Success in the Commissioning and Startup of Capital Projects: Implementing Critical Success Factors



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Achieving Success in the Commissioning and Startup of Capital Projects: Implementing Critical Success Factors

*Research Team 312, Best Practices for Commissioning and Startup
Construction Industry Institute*

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Executive Summary

This implementation resource provides key guidance on how project teams can help ensure success in capital project commissioning and startup. The document is intended to complement or supplement the prior recommendations and learnings from Research Team (RT) 121, *Planning for Startup*. CII established RT 312, *Best Practices for Commissioning and Startup*, to identify the best practices for commissioning and startup (CSU) that define, achieve, and maintain owner operational performance. Through surveys and interviews with CSU experts from CII member companies, the research team identified 16 critical success factors (CSFs) and then validated them through analysis of project performance and external expert feedback.

The introduction of this publication gives an overview of the research purpose and objectives, scope limitations, and research methodology. Chapter 2 presents CSU terminology, CSU phases/milestones, and CSU organizational functions. Chapter 3 defines the 16 CSFs, and discusses their recommended timing, how frequently the industry accomplishes them, barriers to their accomplishment, and their links to project safety and quality. Chapter 4 links the CSFs to the work process model presented in Implementation Resource (IR) 121-2, *Planning for Startup*. Chapter 5 presents a reproducible user-friendly checklist of the CSFs and innovative commissioning technologies. Chapter 6 compares the CSU performance of 26 actual projects to their levels of CSF implementation, providing validation of the CSFs, along with additional insights into both CSU performance and key indicators of CSF achievement. In Chapter 7, four case studies examine four CSU failures, highlighting missing links to critical success factors. Chapter 8 describes five innovative commissioning technologies investigated by the research team. The concluding chapter presents key take-aways from the study. The appendix provides additional ideas on how to advance CSU practice.

1

Introduction

Purpose and Objectives

Successful capital project investment depends on successful project commissioning and startup. RT 121, Best Practices for Commissioning and Startup, defined commissioning and startup (CSU) success in terms of eight different component metrics: 1) product quality; 2) product quantity (or production rate); 3) startup schedule performance; 4) startup safety performance; 5) startup environmental performance; 6) operations team performance; 7) impact of startup on operations; and 8) level of startup effort required.

Yet industry benchmarking data indicate that commissioning/startup performance often falls far short of expectations and that CSU planning and execution efforts are often deficient. Thus, industry is in need of effective guidance on planning and implementing project commissioning and startup. Certainly, organizations should consider how new technologies can leverage the efforts of CSU team members.

The purpose of this research was to understand effective management approaches and new technologies for successful commissioning and startup of capital projects. Specific objectives of the research included the following:

1. Broaden the understanding of key terms pertaining to commissioning/startup/initial operations.
2. Identify critical success factors (CSFs) for step-wise advancement of CSU planning and execution.
3. Understand the current extent of industry accomplishment of the identified CSFs and identify relevant barriers to their successful achievement.
4. Analyze project CSU performance relative to degree of CSF implementation, and thereby determine the relative contribution of CSFs to actual commissioning performance.
5. Understand how the CSFs link to the activities contained in the process model presented in IR 121-2, *Planning for Startup*.
6. Identify innovative technologies for optimizing CSU performance.

Facility owners/operators are the primary intended beneficiaries of this research, especially in the industrial sector. Capital project team members involved in the planning and implementation of facility CSU (representing both contractors and owners) will also benefit from the results.

Scope Limitations

This study focused on commissioning, startup, and preparation for initial operations of industrial facilities, such as petro-chemical, power, water/waste-water treatment, and nuclear plants, among others. In addition, most of the findings are also applicable to systems-intensive building and infrastructure projects, such as pharmaceutical, hospital, and airport projects. Facility operations considerations are limited to relevant issues and opportunities prior to and during operational ramp-up periods, and up to and including final plant performance testing. Steady-state plant operations issues that arise after final performance testing are outside the scope of this study. The scope included best industry practices for commissioning/startup/initial operations that should be performed in all project phases. Some additions and modifications to IR 121-2 have been included in this study, but a comprehensive update/revision of that planning document was outside the scope of this study.

Research Methodology

Figure 1 shows that the RT 312 research methodology involved a mix of literature review, research team model-development, surveys of industry commissioning experts, and several approaches to validation of the team findings. The research team focused on establishing CSU CSFs, starting from an initial listing of 139 potential factors. Industrial commissioning experts then were asked to draw on their experience to estimate the relative contribution of these potential factors to CSU success. With these expert CSF ratings in hand, the research team was able to determine the timing of CSF implementation (within the project context), identify the CSF indicators (or tell-tales) of achievement, assess the frequency of CSF achievement (industry benchmarking), and identify the barriers to implementation for the less frequently achieved CSFs. The team was also able to link the CSFs to the IR 121-2 activity flowcharts and to conduct four detailed commissioning failure mini-case studies, highlighting failures to achieve the CSFs, and links between CSFs and project quality and safety.

The research team then conducted brainstorming sessions, discussions, and analysis to determine indicators of CSF achievement. Research Report (RR) 312-11, *Identification and Implementation of Critical Success Factors in the Commissioning and Startup of Capital Projects*, provides a full account of the research methodology, including details about the literature review, data collection and analysis methods, characterization of data sources, and details on the validation.) Lastly the team developed the CSF indicators checklist tool.

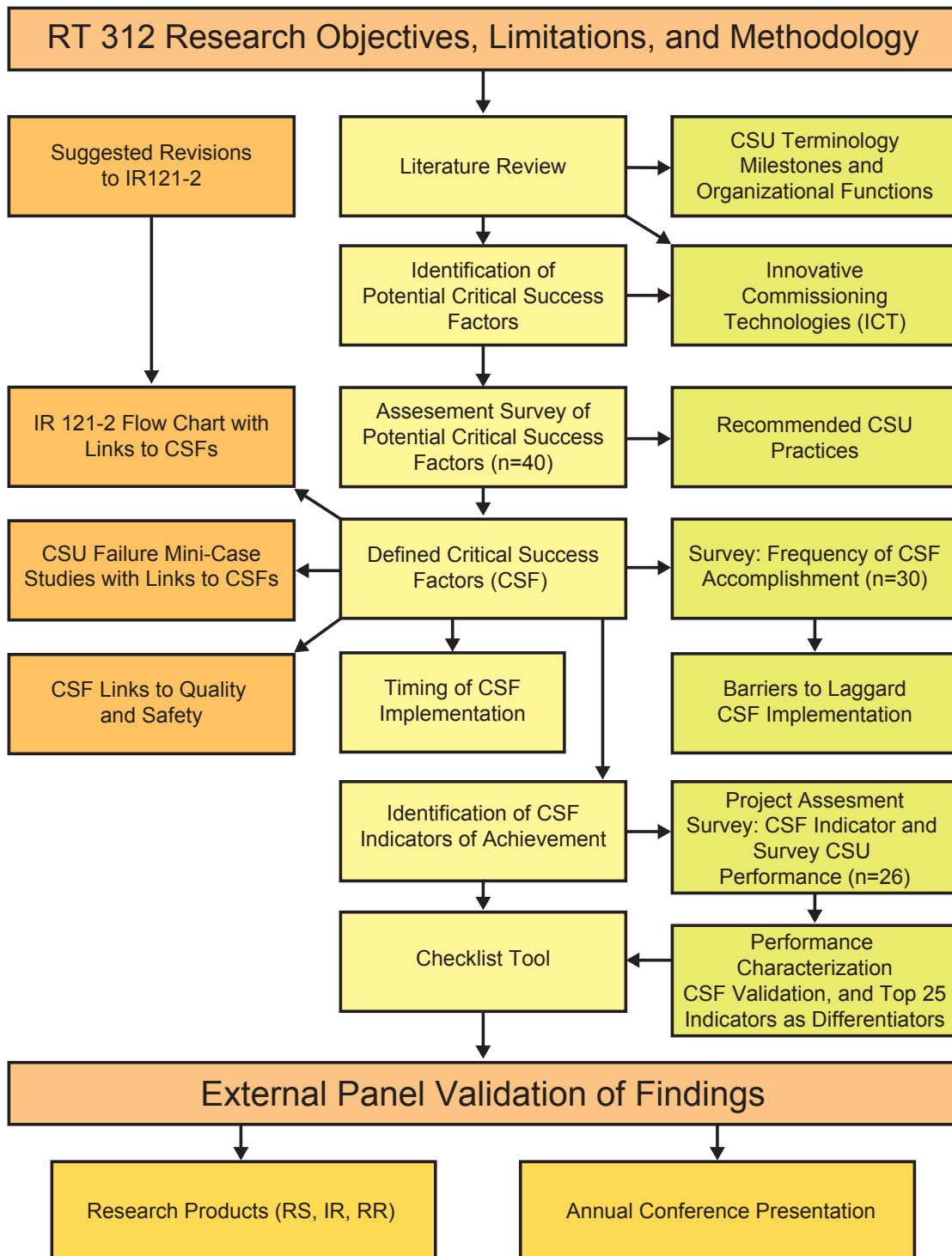


Figure 1. RT 312 Research Methodology

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Commissioning and Startup Terminology and Structures

From the beginning, the research team recognized that better industry alignment on CSU terminology and CSU management system structures would provide a needed foundation upon which to establish or extend CSU best practices. CSU terminology can vary from company to company and across industry sectors; and, because this is particularly true of the terms pre-commissioning and commissioning, RT 312 clarified them with consensus distinctions. (See Table 1.) CSU phase and milestone labels and relationships also vary and, thus, warranted clarification and alignment. (See Figure 2.)

Table 1. Terminology: Pre-commissioning versus Commissioning

Pre-commissioning (Component-level)	Commissioning (Multi-component Integration and System-level)
Scope Description Activities	
• Activities are usually post-mechanical completion (at the component level) but prior to energization and any feedstock introduction. • Activities may or may not be the responsibility of the construction contractor. • Concludes with a ready-for-commissioning certificate for each system. • Rotating equipment: bump for, rotation guards, installed, rotation check, motor bumps, alignment checks, and uncoupled checks	• All construction is complete and verified prior to initiation of commissioning (but post- construction handover). • Energization of equipment starts the commissioning process • Actions immediately prior to startup • Activities are most often the client's responsibility. • Concludes with a ready-for-startup certificate for each system.

Table 1. Terminology: Pre-commissioning versus Commissioning (*Continued*)

Pre-commissioning (Component-level)	Commissioning (Multi-component Integration and System-level)
Key Conclusions	
• Line-vessel cleaning; initial leak checks; non-operating checks, inspections, testing, cleaning, flushing, blowing, drying, adjusting; cold aligning of equipment, piping, instrumentation, electrical systems, cold alignment checks, spring hanger settings, and some equipment tests • Mechanical equipment, wiring checks for installation accuracy; point-to-point continuity checks • Mechanical function tests • Construction rework, as required • All verification tests to ensure equipment is fabricated, installed, cleaned, and tested in accordance with the design • All tests/inspections required prior to any dynamic testing • Function checks accomplished with discipline-specific check-sheets • Power-off checks of equipment, piping, and electrical cable • Non-operating adjustments performed before system turnover • “First fill” (e.g., lubricants, and utility fluids); loading of catalysts, desiccants, polishers, and other fluids	• All energized and/or dynamic tests that verify that each system or subsystem is fabricated, installed, cleaned, and tested in accordance with the design intentions, and that systems are ready for startup • Chemical cleaning and steam blowing • Final leak checking and air freeing; leak and tightness testing • Instrument loop calibration • Checkout of PLC and emergency shutdown system; testing of all safety functions; testing of control functions • Refractory dry-out • Rotating equipment run-in; coupled testing of rotation equipment • Circulation with temporary fluids • Testing of utilities • Testing of control functions and installation of final valve trim

Commissioning and Startup

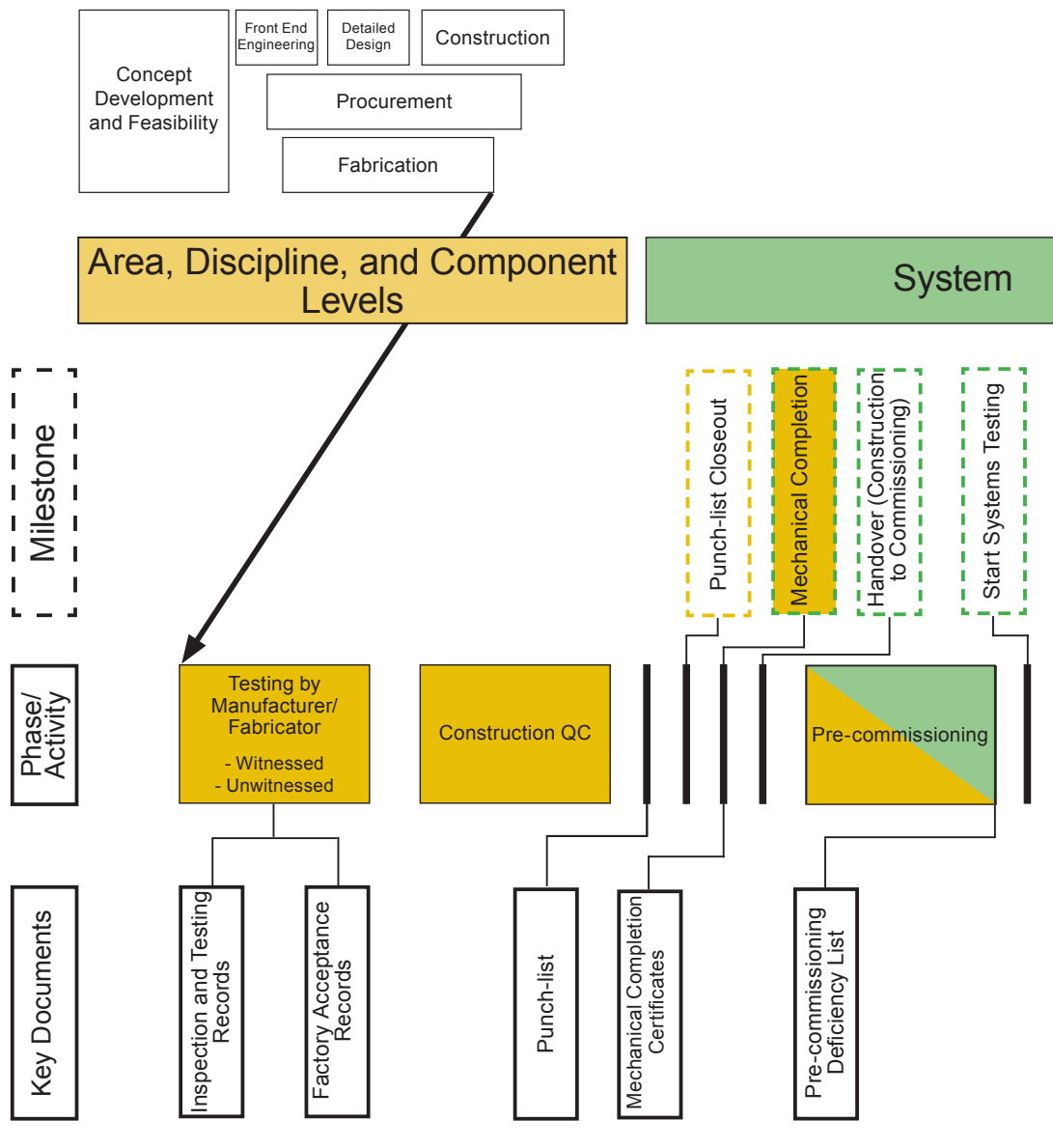


Figure 2. CSU Phases and Milestones

Phases and Milestones

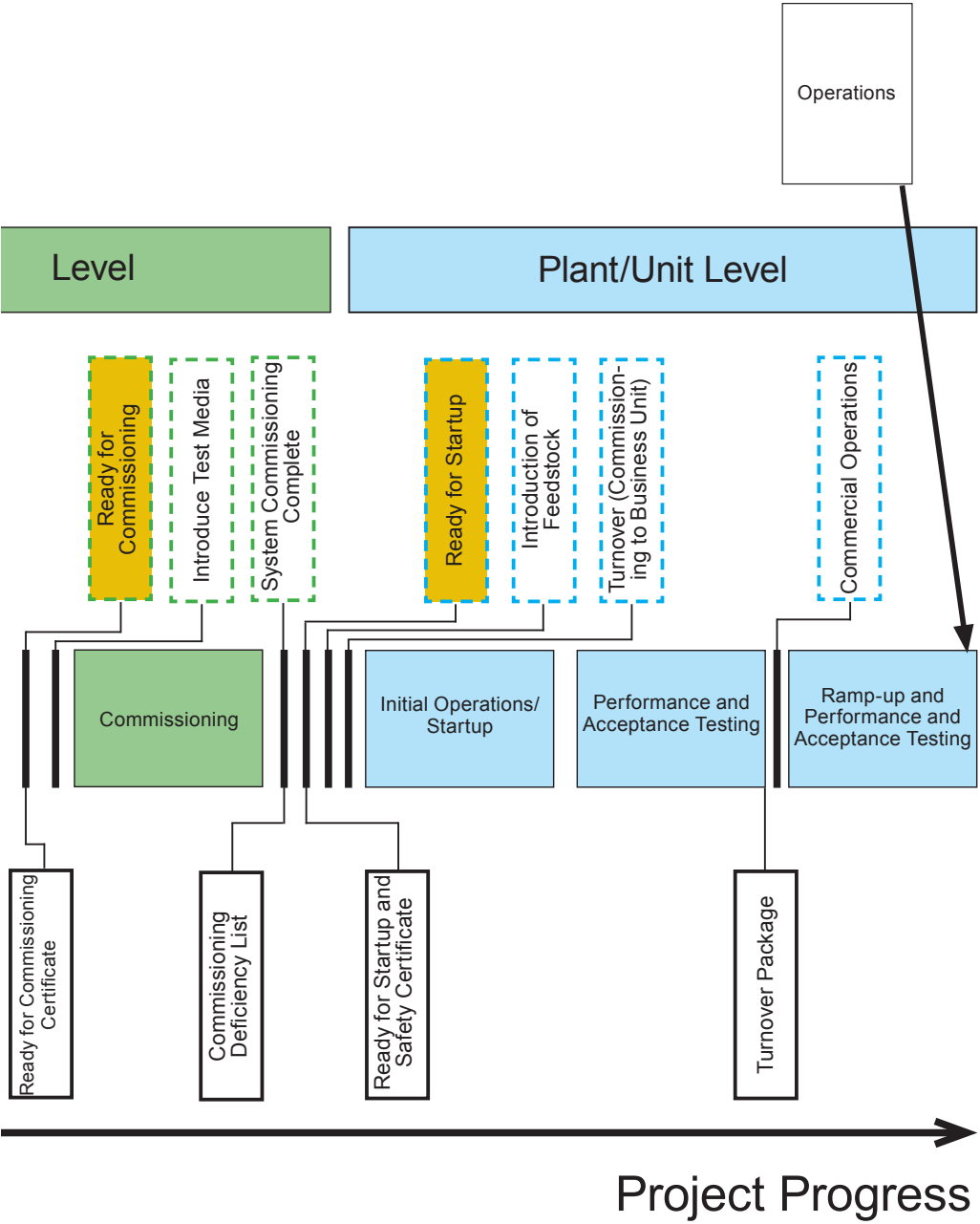


Figure 2. CSU Phases and Milestones

The research team also believed it would help to determine who is typically involved (in some way) in CSU activities. Figure 3 matches these activities to their organizational functions. While the team did not further explore detailed organizational dimensions of CSU, this listing of functions provided a useful basis for subsequent discussions and research developments.

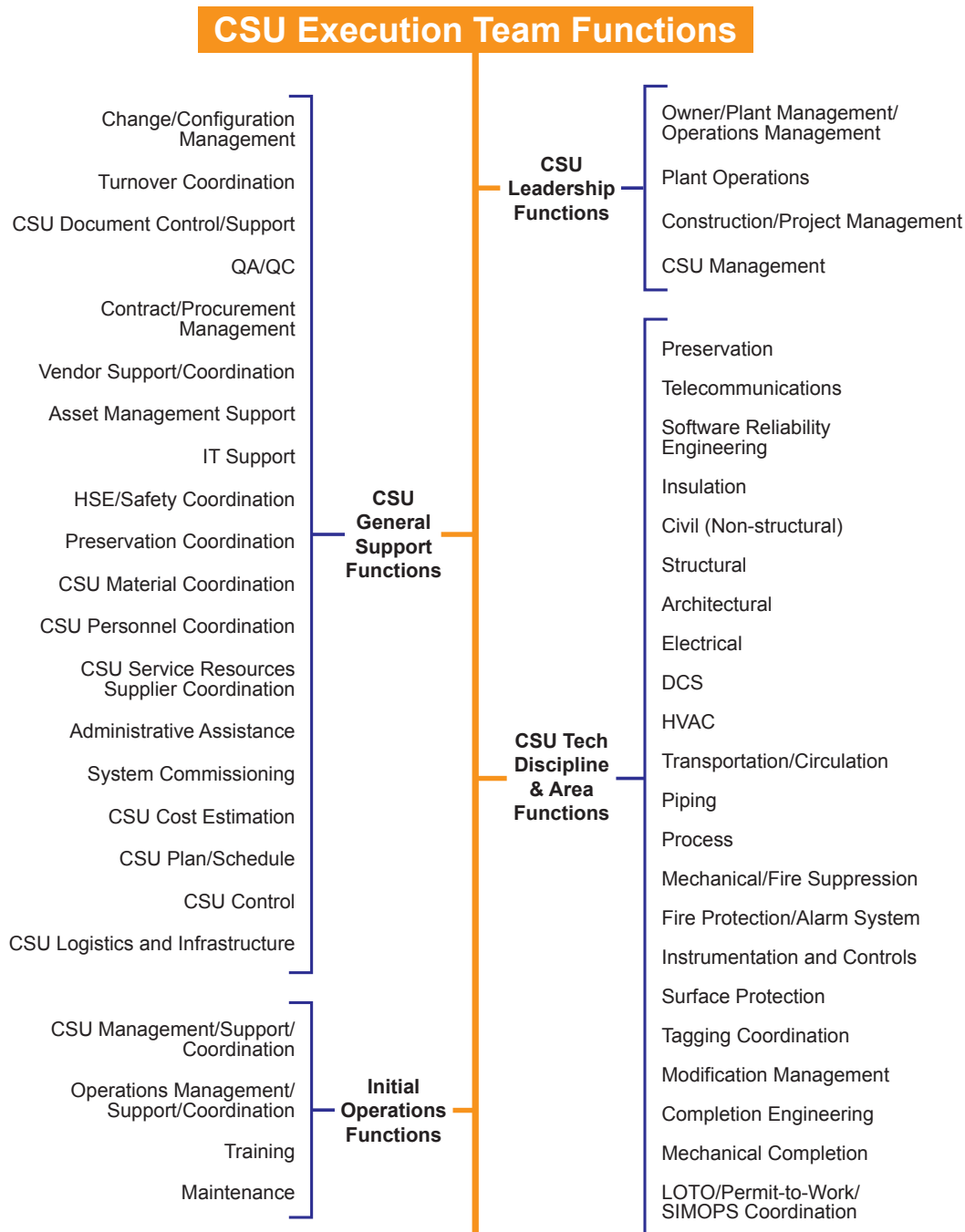


Figure 3. CSU Organizational Functions

3

CSU Critical Success Factors and Implementation

Critical Success Factors for Commissioning/Startup

As mentioned in the previous chapter, the research team isolated 16 CSU critical success factors (CSFs) from an initial list of 139 potential factors. Table 2 presents the CSFs, numbered in order of sequence of implementation on projects, with succinct CSF labels and descriptions. At a high level, these factors focus on leadership, team alignment, integration, collaboration, capability, success criteria, interface management, recognition of value drivers, planning, funding for planning, CSU systems-focus, support tools, and information.

Table 2. Critical Success Factors for Commissioning/Startup

Critical Success Factor	Description
1. CSU Value Recognition	Establish the business case (including CSU staffing plan) for effective CSU leadership. Recognize the value added from successful CSU (e.g., the value of one day of successful operations). Avoid being “dollar foolish”: the owner and all contractors must buy into (and be aligned on) the economics of effective planning, and the investment required.
2. Critical Interfaces on Brownfield Projects	For brownfield projects identify early-on all critical interfaces with existing plant facilities and plant operational approaches. Examples include isolation design, system controls, worker access, permitting, and interim operations, among others.
3. Adequate Funding for CSU	Project funding for CSU must be adequate, budgeted up-front, and preserved. The common threat from failure to do so is a lack of enough operators, which causes subsequent delays in the CSU progress.
4. Alignment among Owner PM, Operations, CSU, Engineering, and Construction	The project and CSU will benefit substantially from getting early alignment among CSU, operations, project management, engineering, construction, and other key stakeholder representatives on the key issues of CSU terminology, CSU success drivers, and CSU strategies. Lack of such alignment may pose a threat to CSU success. Sustained alignment between these entities can only be achieved with effective collaboration throughout the life of the project.
5. CSU Leadership Continuity	Continuity of CSU management leadership throughout the project is critical. The necessary qualifications of the CSU leadership should be well defined.

Table 2. Critical Success Factors for Commissioning/Startup (Continued)

Critical Success Factor	Description
6. System Milestone Acceptance Criteria and Deliverables	Establish specific detailed systems/subsystems acceptance criteria and associated deliverables for each major milestone: mechanical completion, turnover, pre-commissioning, commissioning, and handover. All project parties should understand these expectations.
7. CSU Systems Engineering during FEED	CSU systems Engineering during FEED is the activity of defining CSU systems within a facility. As the design of facilities has a major impact on how they are fabricated, tested, integrated, and started up, effective FEED design efforts can reduce commissioning and startup challenges. Preliminary P&IDs are key documents for this effort.
8. Recognition of CSU Sequence Drivers	The planned sequence of commissioning should be coordinated with construction planners and based on such considerations as construction sequence, plant operations philosophy, ramp-up objectives, plant controls automation objectives, HAZOP awareness, modularization scope, clean-build procedures, sequence of flushing, sequence of leak/hydro testing, preservation steps, system tagging, and sequence of loop checks, among other issues.
9. Detailed CSU Execution Plan	CSU success requires timely and thorough execution planning, which integrates project planning with CSU planning. Execution plans should address the appropriate skill mix necessary in both CSU craft and CSU management. Plant operations must be an effective contributor to this planning effort, and common challenges that must be addressed (in the plan) include Operations staff availability, continuity, authority, breadth of experience, and timeliness of input.
10. Systems-focus in Detailed Design	A systems-focus during design, involving CSU and operations, will raise awareness of how systems will be handed over, tested, and started up. With this approach more design attention will be given to such issues as high/low point drains, removable spools for critical inline equipment, critical isolation points, LOTO requirements/supports, and access for operations and maintenance.
11. CSU Check-sheets, Procedures, and Tools	Ensure component/system functional checkouts include adequate check-sheet criteria, detailed system commissioning procedures, and certifications. Application of innovative CSU technologies will enhance implementation.
12. CSU Team Capability	CSU team has a good understanding of the operations performance metrics-oriented requirements and the CSU activities and deliverables needed to obtain those results.

Table 2. Critical Success Factors for Commissioning/Startup (*Continued*)

Critical Success Factor	Description
13. Integrated Construction/CSU Schedule	A fully integrated construction/pre-commissioning/commissioning schedule is critical to achieving CSU objectives. This schedule should integrate all checks, tests, and approval milestones for each component and all systems, and show development of supportive documentation. CSU acceleration effects from delayed construction are to be avoided.
14. Accurate As-built Information	Accurate as-built drawings and asset database are needed to ensure effective planning, implementation, and closeout of CSU activities.
15. Transition to Systems-based Management	Plan to transition from construction progress tracking on an area basis to a systems-completion basis so that construction forces may be most effectively redirected as needed. Involve CSU staff in construction planning at approximately 60-80 percent system construction complete (for each single major system) in order to help mitigate construction punch list items (with particular early focus on utility systems).
16. Collaborative Approach to Construction-CSU Turnover	CSU managers should work collaboratively with construction managers in managing construction completion and systems turnover. Proactive communications are needed to minimize construction-CSU conflicts.

Timing of CSF Implementation

Proper timing of implementation is key to the effectiveness of each CSF. Figure 4 illustrates the recommended timing of CSF implementation. Three of the 16 CSFs should be fully achieved prior to the initiation of detailed design, and nine of them should be fully achieved prior to the initiation of construction. Many practitioners that recognize these success factors might be surprised at the recommended timing of their implementation. A key finding of this research is that project teams should not delay their implementation of the CSFs.

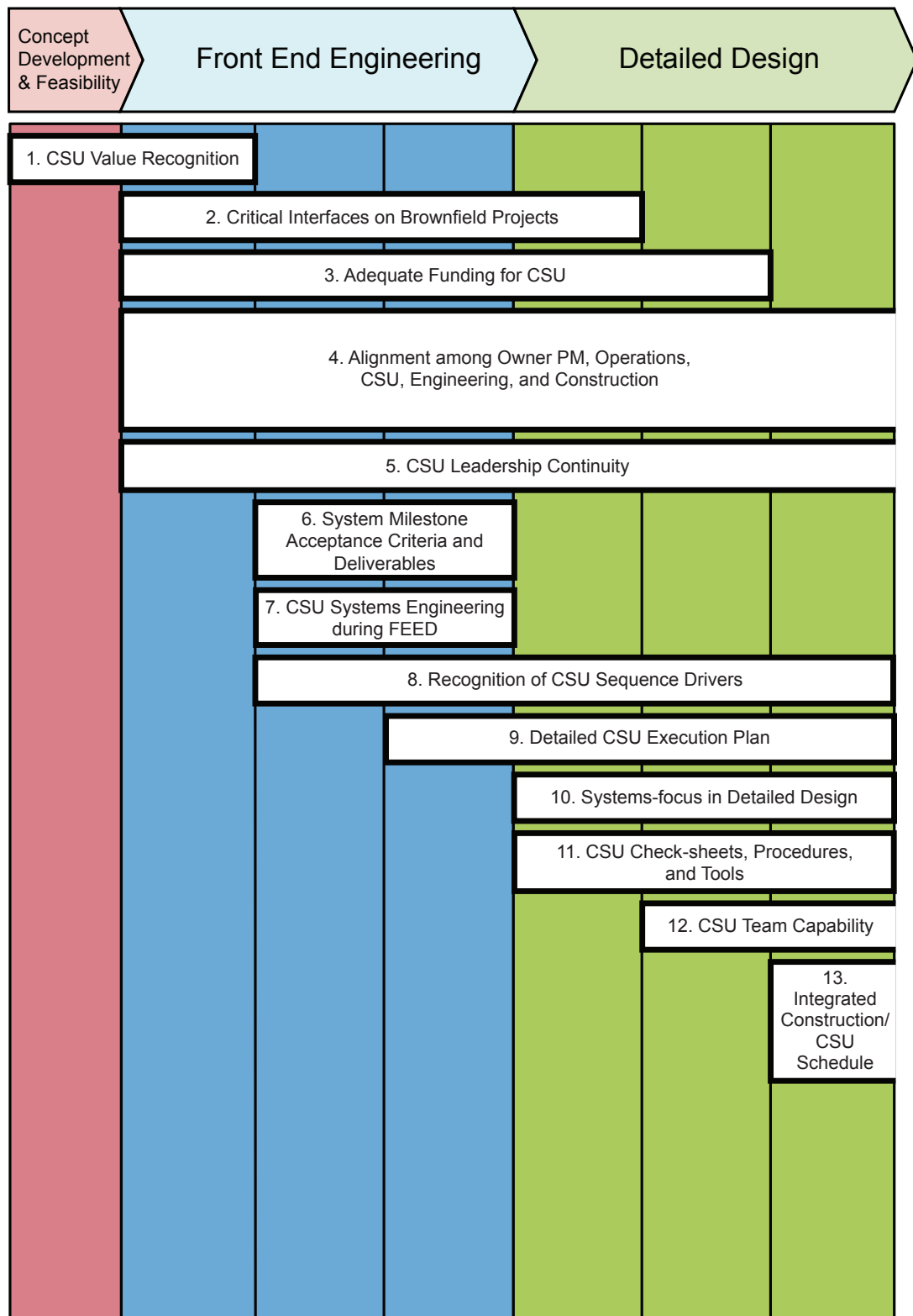


Figure 4. Timing of CSF Implementation

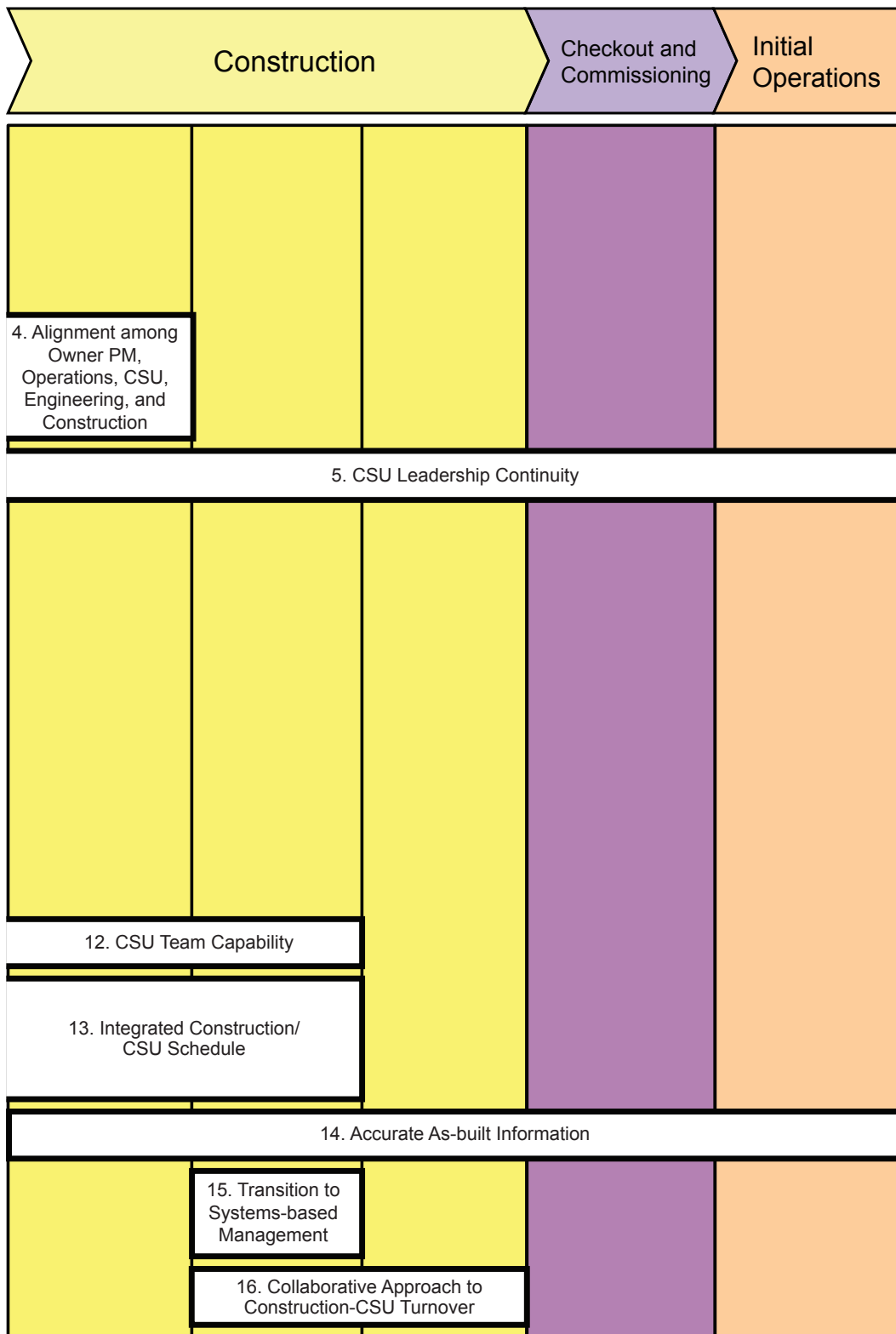


Figure 4. Timing of CSF Implementation

CSF Frequency of Achievement

The research team sought to determine to what extent project teams are currently implementing or accomplishing the CSU critical success factors. To do this, the team surveyed 30 CSU managers on the relative frequency or accomplishment of the CSFs on their projects, and gathered project characteristics from 26 actual projects, noting any CSF indicators of achievement. (See Chapter 6 for more on this project characteristic data.)

A comparison of the analyses of these data indicated that the following CSFs were the least frequently achieved:

1. System Milestone Acceptance Criteria and Deliverables
2. CSU Value Recognition
3. Adequate Funding for CSU
4. CSU Systems Engineering during Front End Engineering Design (FEED)
5. Systems-focus in Detailed Design
6. CSU Leadership Continuity.

This finding shows that more than a third of all CSFs are challenging to implement. To provide further insight into these challenges, the team examined implementation barriers to these six CSFs.

Barriers to the Implementation of Less Frequently Accomplished CSFs

The research team brainstormed a large number of potential barriers to CSF achievement and refined the list down to those considered most significant. (See Table 3.) Practitioners should first be aware of these barriers and then confront and mitigate them at the earliest opportunity.

Table 3. Barriers to Less Frequently Accomplished CSFs

Critical Success Factor	Barrier to Achieve CSFs
1. CSU Value Recognition	1. Too little focus on “doing the right things” (investing in CSU)
	2. Many stakeholders and project managers do not understand the value proposition; they are “penny-wise and pound-foolish.”
	3. Project managers are stuck in old paradigms.
	4. Difficulty quantifying relationship between CSU resourcing/ planning and the benefits of effective CSU.
3. Adequate Funding for CSU	1. Funding is not proportionate to project complexity and size.
	2. Failure to recognize fully the value of successful CSU.
	3. Project funding stress due to construction overruns
	4. Overly simplistic estimating methods (percentage of TIC)
	5. Failure to include funding for specialty SMEs needed and/or specialty training needed
5. CSU Leadership Continuity	1. Lengthy duration of projects, from project planning to end of startup
	2. HR effects and difficulty in achieving continuity: routine promotions, retirements, and job changes
	3. Lack of appreciation for the importance and impact of leadership continuity
	4. No established training/mentoring program for CSU team members
	5. Lack of early-phase project funding leading to the delayed establishment of the CSU team
6. System Milestone Acceptance Criteria and Deliverables	1. Lack of systems definition during FEED
	2. CSU planning team not established during FEED
	3. CSU is not involved in execution contract development, so it may not be included in the contractual scope of work.
	4. Lack of timely involvement of operations in establishing acceptance criteria
	5. Challenges in keeping the acceptance criteria current, due to design/scope changes

Table 3. Barriers to Less Frequently Accomplished CSFs (Continued)

Critical Success Factor	Barrier to Achieve CSFs
7. CSU System Engineering during FEED	1. The “It’s too early” paradigm (“We don’t have enough information”)
	2. Lack of understanding of the importance of early systemization and needed planning resources
	3. No CSU visibility, compared to constructability and other best practices
	4. Lack of a champion at this time
	5. Failure to effectively transfer CSU knowledge to engineering personnel
10. System-focus in Detailed Design	1. Late engineering deliverables tend to push this into construction
	2. Lack of continuity in engineering resources and contractors
	3. Package units that lack system definition; poor associated assumptions
	4. Lack of a champion at this time
	5. Failure to transfer CSU knowledge effectively to engineering personnel

Indicators of CSF Achievement

The 16 CSU critical success factors provide meaningful insight and substantial guidance for project teams seeking high levels of CSU performance. Follow-through efforts by management should pertain to CSF implementation and periodic assessment of actual CSF achievement. To support this recognition and assessment of CSF implementation, RT 312 formulated 45 CSF achievement indicators. These tell-tales offer strong evidence of actual CSF achievement. Table 4 matches them with their associated CSFs. The research indicated that 30 of the 45 indicators are excellent differentiators between CSU success and failure. Project teams will find these indicators to be particularly informative in their assessments of actual CSU preparedness. (See Chapter 6 for a detailed discussion of the 30 indicators.)

Table 4. Indicators of CSF Achievement

Critical Success Factor	CSF Indicators of Achievement	Top 30 Indicator
1. CSU Value Recognition	1.1 CSU manager is on the project organizational chart at the start of front end engineering.	✓
	1.2 Prior to the start of front end engineering, approved CSU budget and schedule are in hand for CSU planning work.	
	1.3 Project leadership is very familiar with the venture value that would be lost from a one-day delay in startup of operations.	
2. Critical Interfaces on Brownfield Projects	2.1 Project team has identified all tie-ins and individual shut-downs by 30-percent detailed design complete; and these have been integrated into the construction-CSU integrated schedule.	✓
	2.2 All construction-CSU physical access constraints due to brownfield conditions have been identified by 30-percent detailed design complete.	
	2.3 System boundaries and isolations are developed with full understanding of brownfield operations/ controls conditions.	
	2.4 All project team members understand site permitting requirements.	
3. Adequate Funding for CSU	3.1 By the end of front end engineering, the CSU budget has been derived from knowledge of CSU strategy and scope of work, and if needed CSU resources, not simply a percentage of TIC.	✓
4. Alignment among Owner PM, Operations, CSU, Engineering, and Construction	4.1 The CSU philosophy/strategy/execution plan has been reviewed/approved by all stakeholders, and signatures are affixed.	✓
	4.2 Repeated confirmation of alignment is achieved.	✓
	4.3 Critical CSU input has been acquired for engineering design reviews, engineered equipment purchases, construction sequencing, and schedules.	✓
	4.4 Several CSU joint meetings were held in which all stakeholders were present. These were initiated early and were repeated throughout planning, design, and construction phases.	

Table 4. Indicators of CSF Achievement (*Continued*)

Critical Success Factor	CSF Indicators of Achievement	Top 30 Indicator
5. CSU Leadership Continuity	5.1 A CSU manager was assigned at the start of front end engineering and remained with the project through to initial operations.	✓
	5.2 The qualifications and the planned tenure of the CSU manager were well-defined by early front end engineering.	✓
6. System Milestone Acceptance Criteria and Deliverables	6.1 System acceptance criteria were incorporated into the contract with the execution contractor.	✓
	6.2 System/subsystem acceptance criteria were well documented prior to bid document submission, and key parties were aligned on the criteria by the end of front end engineering.	
7. CSU System Engineering during FEED	7.1 Formal CSU design review has occurred by the end of front end engineering.	✓
	7.2 By the end of front end engineering, system (and module) boundaries are identified on P&IDs and electrical one-line diagrams.	
	7.3 CSU manager was accountable for leading the team through the systemization process, involving operations, maintenance, and CSU resources.	
	7.4 Preliminary CSU sequence was defined by end of front end engineering.	
8. Recognition of CSU Sequence Drivers	8.1 A methodical approach was used to develop the project's CSU sequence (including all system, subsystems and related dependencies), with formal recognition of all critical sequences and was finalized by end of detailed design.	✓
	8.2 The formulation of CSU sequence was completed by the end of detailed design and took into consideration timely completion of life-safety and process safety systems, control systems, utility systems, and process systems, among others.	✓